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NOL HYPERSONIC SHOCK TUNNEL FACILITIES

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DECEMBER 1963

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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Ballistic Research Report No. 120

NOL HYPERSONIC SHOCK TUNNEL FACILITIES

Prepared by:
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ABSTRACT: This report includes a description of the capabilities and the limitations of the NOL Hypersonic Shock Tunnel facilities presently in operation, and a discussion of some of the associated instrumentation used with these facilities.

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U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOL HYPERSONIC SHOCK TUNNEL FACILITIES

This report describes the NOL Hypersonic Shock Tunnel Facilities which have been used in numerous aerodynamic studies sponsored by the Re-Entry Body Section of the Special Projects Office, Bureau of Naval Weapons, under the Applied Research Program in Aeroballistics.

The authors wish to acknowledge the help of Mr. D. F. Gates who supplied the mathematical computations and graphs for the shock tunnel ranges of operation, Messrs. B. J. Crapo, Q. N. King and C. G. Holthaus for their contributions to the electronic instrumentation, and Mr. M. W. Wahler for his aid in illustrating this report.

R. E. ODENING
Captain, USN
Commander

A. E. Seigel
A. E. SEIGEL
By direction

CONTENTS

INTRODUCTION

The shock tunnel facilities at the Naval Ordnance Laboratory consist of the 1.5-in. Hypersonic Shock Tunnel No. 1, the 1.5-in. Hypersonic Shock Tunnel No. 2, and the 4-in. Hypersonic Shock Tunnel No. 3. This report deals with the physical description of these facilities and it includes a summary of their aerodynamic and gas dynamic capabilities. The report is divided into two parts, the first dealing with the 1.5-in. facilities while the second deals with the 4-in. facility. The characteristics of these tunnels appear in tabular form in figure 1. Photographs of the three facilities appear in figures 2, 3, and 4.

THE 1.5-in. HYPERSONIC SHOCK TUNNELS

The two 1.5-in. Hypersonic Shock Tunnels have similar dump tanks and low-pressure sections. The dump tanks for both tunnels are six feet in diameter and 25 feet long, and have identical window sections.

Figure 5 shows one of the many possible window arrangements for either of the 1.5-in. Shock Tunnels. Four 18-inch diameter circular discs are carried in a long rectangular plate which can be moved about six inches either side of its center position. Each dump tank is provided with two sets of discs having eight-inch diameter window ports. In one set the port is located at the center of the disc, while in the other set it is four inches off-center. The remaining discs have no window ports. Flat rubber gaskets provide vacuum seals around the rectangular plate and the 18-inch discs. Sealing of the window glass is achieved with an "O" ring around the circumference and a flat rubber gasket over the outside face of the window. The 18-inch window discs fit any of the 18-inch openings in any of the rectangular plates. The discs carrying the off-center window ports can be rotated so that the center of the window will describe a complete circle about the center of the disc. The many adjustments possible with this window assembly permit the photographic observation of flow phenomena at any point in the test section over a seven-foot range. Either shadowgraph or schlieren techniques may be used in the tunnels, and single frame or multiple exposures are possible. Multiple exposures are obtained with: (1) the Beckman Whitley Model 192 rotating mirror camera, capable of recording photographs at a rate of 1.25 million frames per second; and (2) the Beckman Whitley Dynafax camera, having a capability of 25,000 frames per second. Continuous streak (smear) pictures of motion in the test section can be made with the AVCO type DC-060 Model 1 rotating drum camera. A high energy square wave light pulse generator, which was designed and constructed for this purpose at NOL, provides a light pulse lasting from one to three milliseconds. Using this combination of a long duration high energy light source and either the multiple exposure or the continuous streak cameras, one may obtain photographic records of the flow during the entire blowing time of any of the tunnels.

The low-pressure sections of the two 1.5-in. Shock Tunnels are nominally 200 calibers (300 inches) long. Piston-type pressure gages (refs. (1), (2), and (3)) are used to monitor the pressure at five locations along the low-pressure section of the 1.5-in. Hypersonic Shock Tunnel No. 1 and at six locations along the low-pressure section of the 1.5-in. Hypersonic Shock Tunnel No. 2. In both tunnels the pressure gage station nearest the muzzle diaphragm contains two gages in the same vertical plane.

Pressure is usually monitored simultaneously at each end of the high-pressure chamber in both shock tunnels. Since the high-pressure section diaphragm opens before the gas is completely burned, the rear gage normally reads higher by several thousand psi (ref. (3)). Typical pressure traces from the driver section of the 1.5-in. Hypersonic Shock Tunnel No. 2 are shown in figure 6.

In Shock Tunnel No. 1 a combination of eight ionization and two pressure-sensitive probes (ref. (4)) are used along the low-pressure chamber to detect the passage of the shock-wave in the working gas. The two pressure-sensitive shockwave detectors are located in the last two stations. In Shock Tunnel No. 2 only pressure-type shockwave detectors are used at the eight stations along the low-pressure section. The ion-sensitive probes do not function reliably at Mach numbers below 4.5 due to the limited ionization. At higher Mach numbers these probes tend to be triggered early when used near the metal diaphragm at the end of the low-pressure section of the 1.5-in. Hypersonic Shock Tunnel No. 1. This results in an apparent higher shock velocity at the last station (ref. (3)). Both the pressure-sensitive and ionization probes were designed to fit the same holes in all positions along the low-pressure section of the tunnels. The electronic components associated with these probes, however, are different, and must be changed when changing probe type. Both types of shockwave detectors emit electrical pulses which are amplified and fed to time-interval meters which in turn provide the data for determining shockwave velocity and attenuation.

Figures 7 and 8 show the physical location of the piston-type pressure gages and shockwave detectors.

The 1.5-in. Shock Tunnels are usually operated with a combustible mixture of hydrogen, oxygen, and helium as the driver gas. Ignition of the mixture is achieved with an exploding-foil tape consisting of 0.4 mil aluminum foil backed by cellophane tape 1/2 inch wide (fig. 9). Relatively high resistance ignition points are formed at regular intervals along the tape by punching 1/4-inch diameter holes through the aluminum foil and cellophane tape, and then scraping away the foil from the tape on one side of each hole. The distance between ignition points is approximately 5 inches on the tape for the 1.5-in. Hypersonic Shock Tunnel No. 1, and about 6.9 inches on the tape used in the 1.5-in. Hypersonic Shock Tunnel No. 2. The suspension system, which supports the tape along the axis of the high pressure chamber, consists of the breech plug, two stainless-steel rods and a knife edge. The rods are threaded at one end and have a slot cut in the other. A rigid frame is obtained when the rods are screwed into holes on either side of the breech plug, silver soldered in place, and the knife blade is then silver soldered into the slots in the other end of the rods. Since the pieces are all silver soldered together, a positive electrical path is assured. A nylon and phenolic insulated steel electrode is located in the center of the breech plug. The tape is suspended between this electrode and the center of the knife edge with one ignition point as near each connection point as possible. Figure 10 is a photograph of a typical tape suspension system with the tape fastened in place. When the capacitor is connected to the breech plug and discharged across the tape, the narrow bridge of aluminum foil at each ignition point explodes violently. The arcs thus created at these points ignite the gas, which burns along with the aluminum foil and cellophane tape. Smooth ignition is obtained when the capacitor is charged to a voltage sufficient to provide an energy of approximately 10 joules for each ignition point.

The restriction and nozzle throat detail of the 1.5-in. Hypersonic Shock Tunnel No. 2 is shown in figure 11. Both tungsten and molybdenum are used as nozzle throat materials, since they exhibit less than one percent erosion in the .250-inch throat diameter per shot. Typical reservoir conditions encountered by these materials are 20,000 psi and 12,000°F, with a driven gas flow of two milliseconds duration. Tungsten is the throat material most generally used at the present time.

The 1.5-in. Hypersonic Shock Tunnel No. 1 is operated without a restriction, the working gas being allowed to expand freely into the test section. The original driver sections of both 1.5-in. Hypersonic Shock Tunnels were 40 inches long and 3.75 inches in diameter. The 40-inch driver section of the 1.5-in. Hypersonic Shock Tunnel No. 1 was replaced with a driver section 80 inches long and 3.75 inches in diameter in order to extend the usable blowing time with shock velocities as low as Mach 4. The effect of chamber lengths on the test section is shown by the typical Pitot traces in figure 12.

THE 4-in. HYPERSONIC SHOCK TUNNEL NO. 3

The 4-in. Hypersonic Shock Tunnel No. 3 high-pressure chamber, a modified 8-inch naval rifle breech, is 10 inches in diameter and 144 inches long. Driver gas combustion pressure is measured with a piston-type pressure gage mounted in the breech obturating cup. Gas loading of the high-pressure chamber is accomplished through two openings in the breech obturating cup. The diaphragm between the driver and driven section is a flat stainless-steel plate grooved on one side so that four petals are formed when it folds back. In some cases the flat diaphragm may be prebulged to a hemispherical shape with oil pressure (fig. 13). The diaphragm is mounted in a combination diaphragm former-obturating cup, which in turn is inserted into the forward end of the high-pressure section. The low-pressure section is mounted on stanchions which are equipped with rollers which permit it to be moved back and forth readily. Once the high-pressure diaphragm is in place, the low-pressure section is pulled into place and rotated to engage interrupted threads which lock it into position.

Piston-type pressure gages are mounted at eight locations along the driven section, and shock velocity is monitored by pressure-sensitive shockwave detector probes at 13 points. The location of these gages and probes is shown in figure 14. The tunnel is presently set up to operate as a restricted tunnel with a nozzle throat diameter of .500 inch. The flow expands into an axisymmetrical two-dimensional contoured nozzle which is designed to provide a 20-inch test rhombus of parallel flow. The coordinates for this nozzle were determined through the use of an IBM 7090 computer program (ref. (5)). Analytical fits to the real-gas data for air were used to compute the isentropic expansion from the supply conditions. The nozzle core was then determined by the method of characteristics with a correction added to the core to account for the real-gas turbulent boundary layer. Figure 15 shows the mechanical arrangement of the reflecting surface, nozzle throat and contoured nozzle. Free jet expansion may be achieved in this tunnel by removing the contoured nozzle from the dump tank and exchanging the short section at the end of the barrel for one that will hold the muzzle diaphragm. Several days are required to switch from one mode of operation to the other.

The dump tank of this tunnel is 8 feet in diameter and 50 feet long. There are three sets of fixed 12-inch diameter window ports along each side of the dump tank. These ports represent Mach 8, Mach 12, and Mach 15 positions when the tunnel is operated in the free jet expansion mode. The ports corresponding to the Mach 12 position are used when the shock tunnel is operated in a restricted fashion. At the present time, because of the inherent detonation problem associated with oxygen-hydrogen-helium mixtures at high pressures and large chamber volumes, the tunnel is operated with a gunpowder-helium driver and primer ignition.

When gunpowder is used, it is spread evenly on the bottom of the chamber along its entire length. Because of its fast burning qualities, Hercules Unique gunpowder was chosen for this application. No experimental investigation has been carried out in this facility to determine whether more efficient gunpowders are available for heating the helium. The powder is ignited by three primers placed at uniform intervals along the chamber. The primer holders are silver soldered to an axial primer rod (fig. 16) and the primers are mounted in them and pointed downward so that the primer flashes are aimed directly at the powder layer when the gun is fired. Originally 30 primers were used for each shot. However, more uniform burning was obtained when the number of primers was reduced to three.

At the present time the use of a hydrogen-oxygen-helium gas mixture for the driver gas of the 4-in. Hypersonic Shock Tunnel No. 3 is not contemplated. However, should the state of the art improve to the extent that detonations could be controlled in large volumes at high pressures, the more efficient hydrogen-oxygen-helium mixture will once again be considered.

REFERENCES

1. Dawson, V. C. D., "Piston Type Strain Gages," NAVORD Report 6251, Jan 1959

2. Dawson, V. C. D., "Pressure-Gage Design for the Measurement of Pressures in Shocktube Wind Tunnels, Shocktubes and Guns," NAVWEPS Report 7326, Jan 1961

3. Aronson, P. M., "Pressure and Heat Transfer Instrumentation Used in the NOL Hypersonic Shock Tunnels," Proceedings of the Fourth Shock Tube Symposium, 18-20 Apr 1961

4. Marshall, J. M., "A Pressure-Sensitive Detector for Use in Shock-Velocity Measurements in Shocktubes and Tunnels," NOLTR 61-117, Feb 1962

5. Enkenhus, K. R., and Maher, E. F., "The Aerodynamic Design of Axisymmetric Nozzles for High Temperature Air," NAVWEPS Report 7395, Feb 1962

ILLUSTRATIONS

	1.5-in. HST # 1 Unrestricted	1.5-in. HST # 2 Restricted	4-in. HST # 3 Restricted	Unrestricted
Supply Tube Size	1.5-in. dia. 300-in. long	1.5-in. dia. 300-in. long	4-in. dia. 732-in. long	4-in. dia. 732-in. long
High-Pressure Chamber Size	3.75-in. dia. 80-in. long	3.75-in. dia. 39.5-in. long	10-in. dia. 144-in. long	10-in. dia. 144-in. long
Type	Blowdown	Blowdown	Blowdown	Blowdown
Mach Number Range	8 - 15	11 - 12	12	6 - 13.5
Blowing Time (Milliseconds)	1.2 - 0.4	1.7	3 - 4	3 - 1
Combustion Temperature	2400°C	2400°C	2400°C	2400°C
Combustion Pressure	40,000 psi	40,000 psi	20,000 psi	20,000 psi
Equivalent Supply Temperature	1482°C - 9427°C	6700°C	6700°C	1316°C - 8316°C
Equivalent Supply Pressure (Atmospheres)	11,000 - 3400	1250	730	5000 - 2600
Reynolds Number Per Foot	Mach 8 - 3.5×10^7 2.5×10^6 Mach 15- 6×10^6 1×10^6	Mach 11.3 - 7.5×10^4	Mach 12 - $1.B \times 10^4$	Mach 6 - 4×10^7 1×10^7 Mach 12 - 5×10^6 1.2×10^6

FIG. I CAPABILITY CHART FOR THE N.O.L. HYPERSONIC SHOCK TUNNEL FACILITIES.

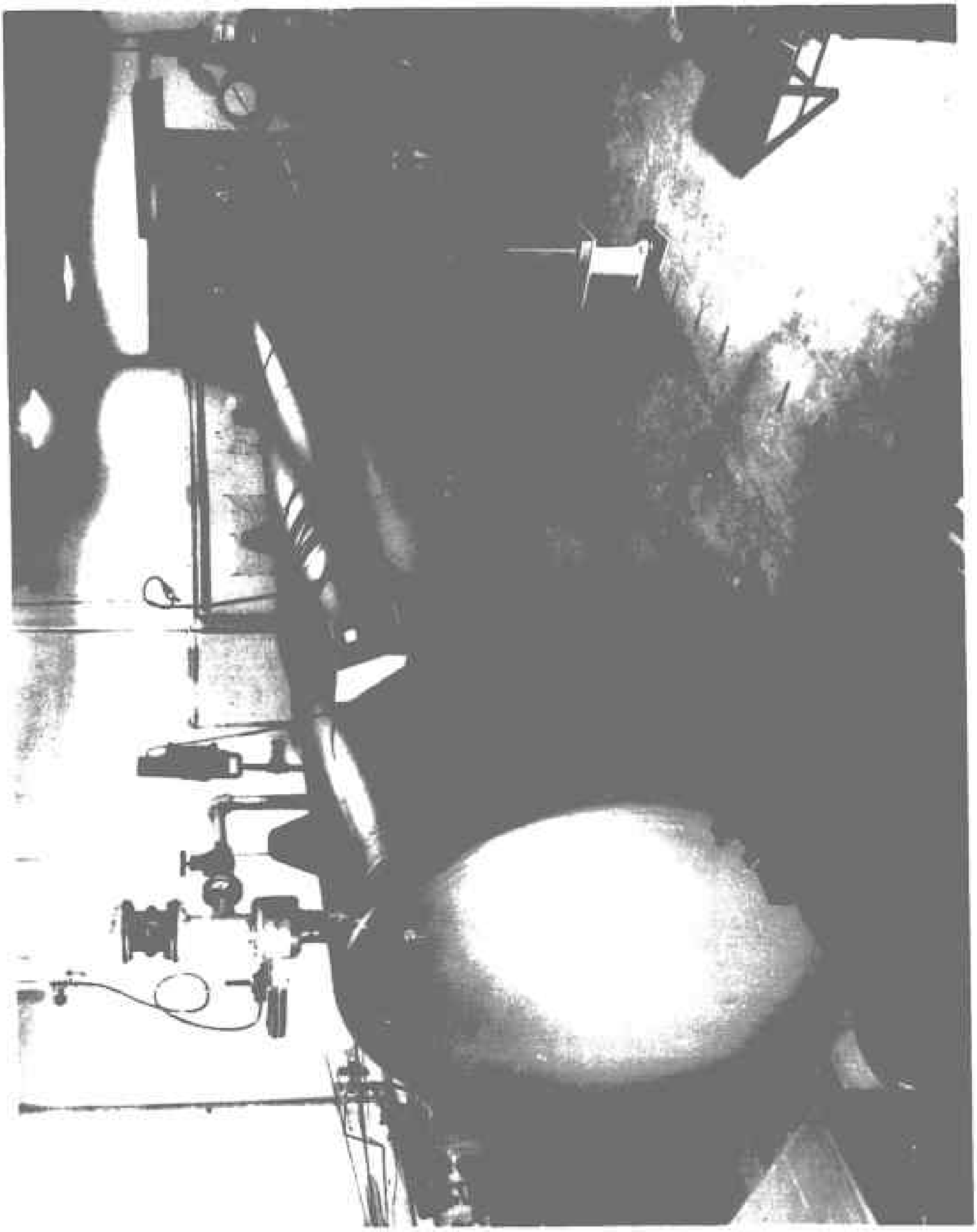

FIG. 2 1.5-IN. HYPERSONIC SHOCK TUNNEL NO. 1.

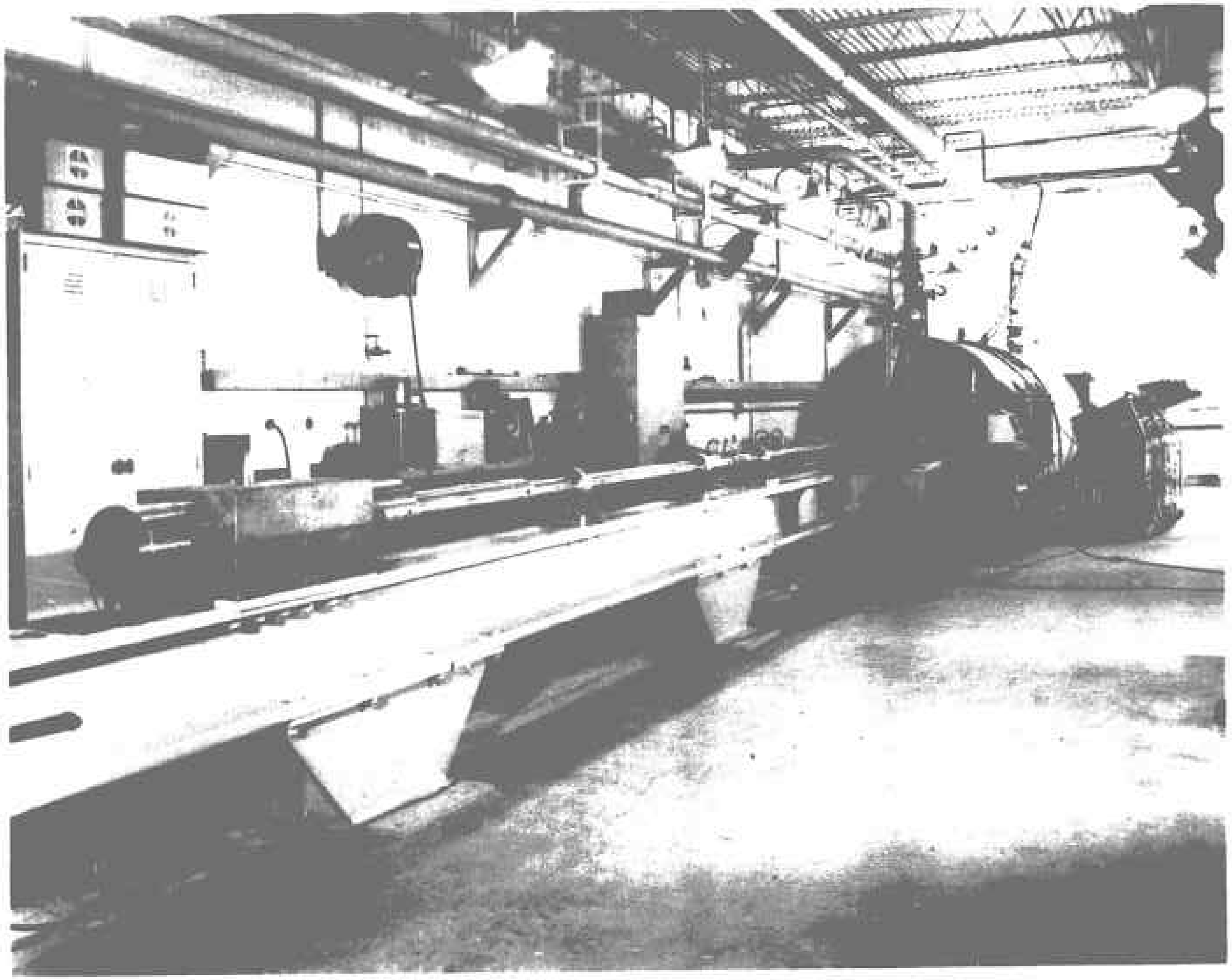

FIG. 3 1.5-IN. HYPERSONIC SHOCK TUNNEL NO. 2.

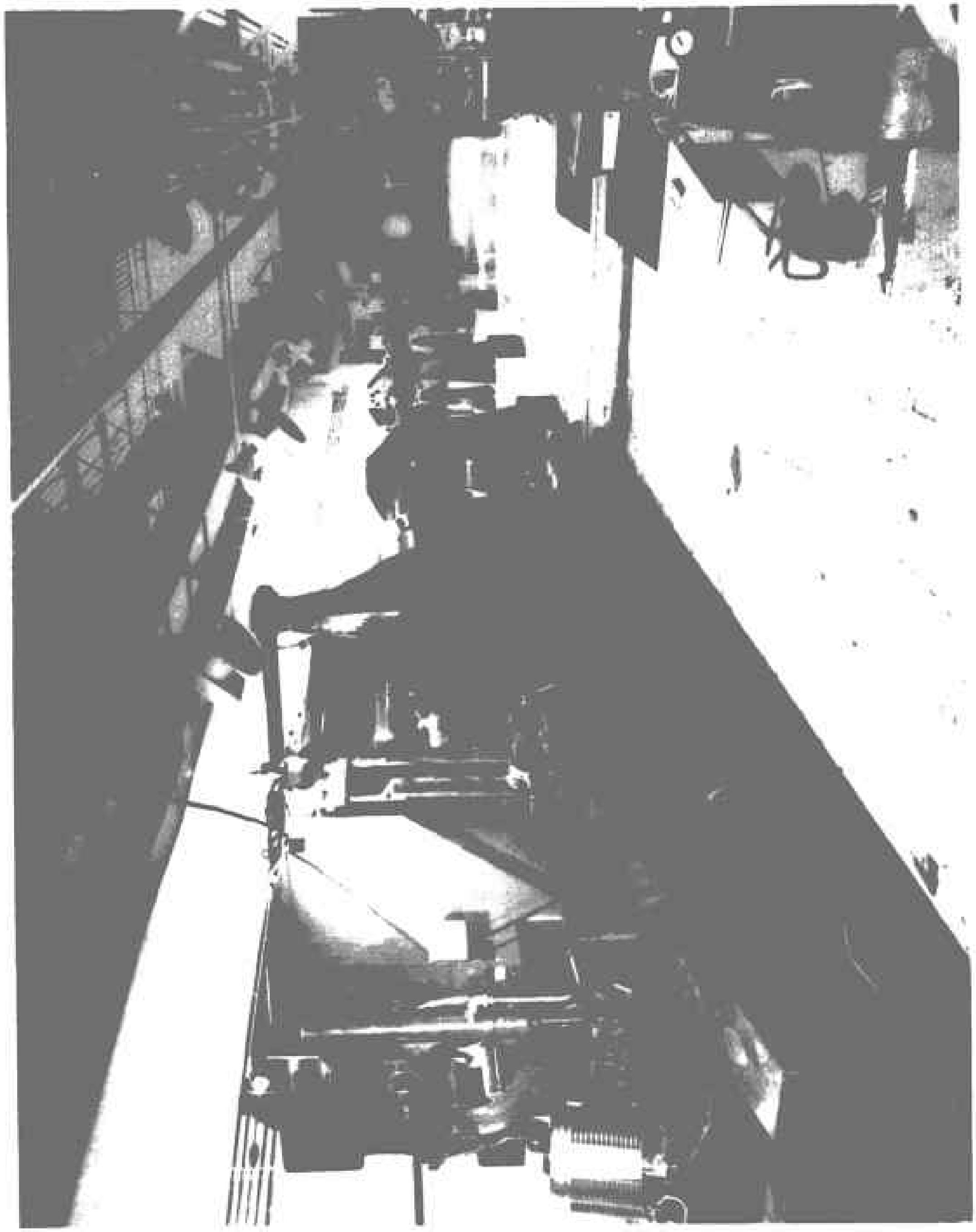

FIG. 4-IN. HYPERSONIC SHOCK TUNNEL
NO. 3.

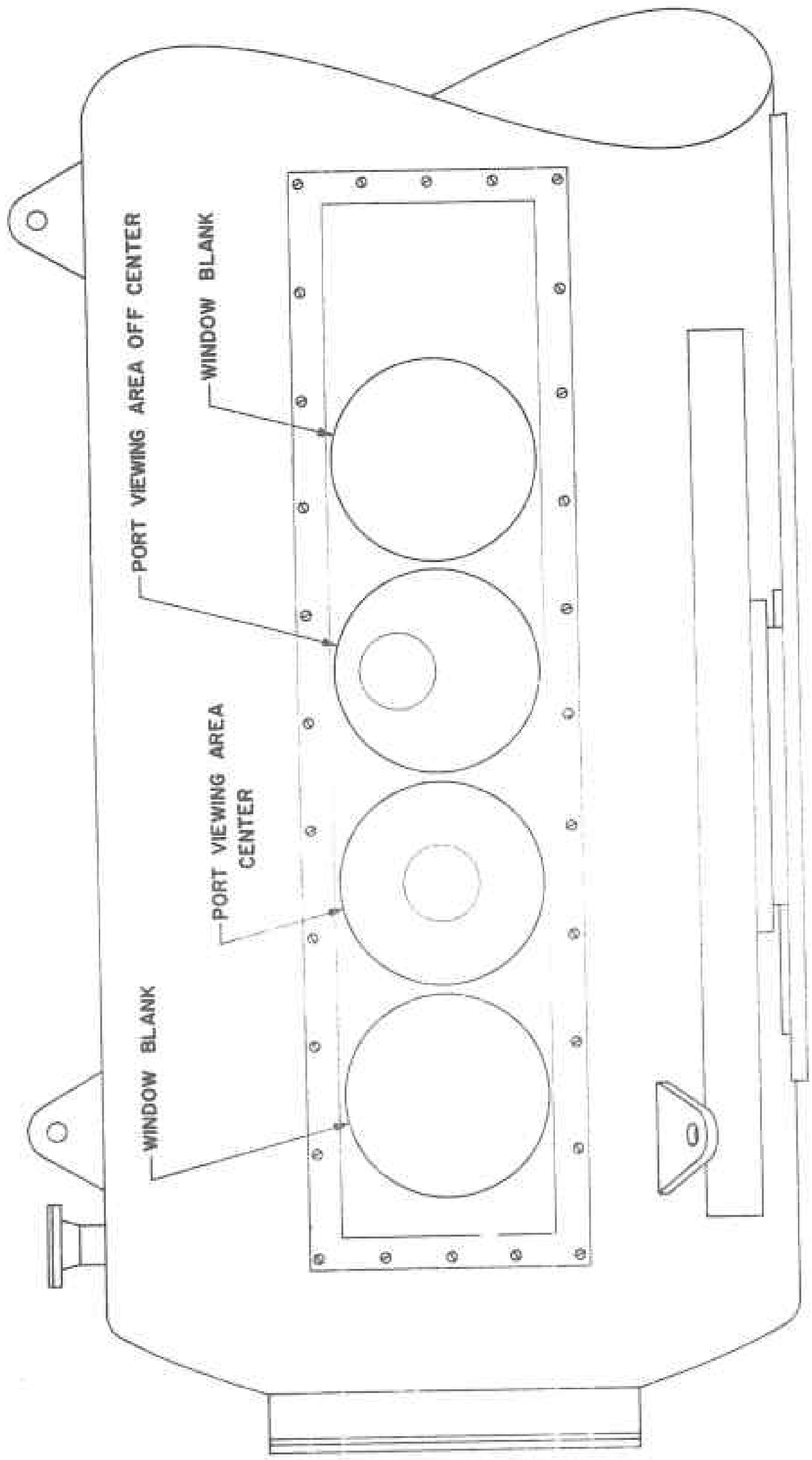

FIG. 5 WINDOW SECTION OF DUMP TANKS FOR THE 1.5-IN. HYPERSONIC SHOCK TUNNELS No. 1 AND No. 2.

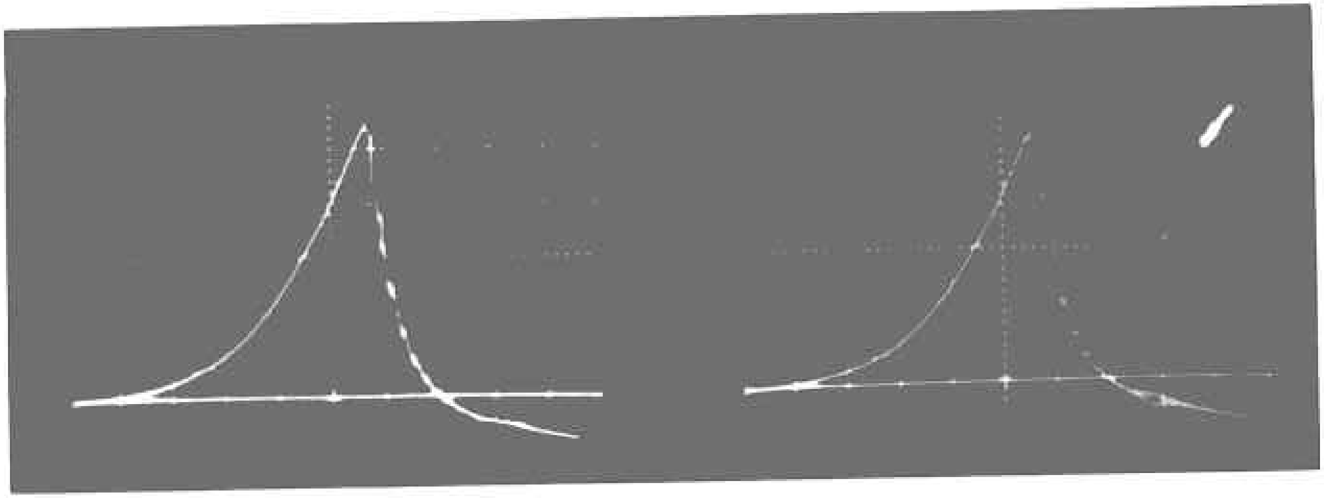

FIG. 6 TYPICAL PRESSURE TRACES FROM DRIVER SECTION OF THE 1.5-IN. HYPERSONIC SHOCK TUNNEL No. 2 USING EXPLODING FOIL IGNITION TAPE.

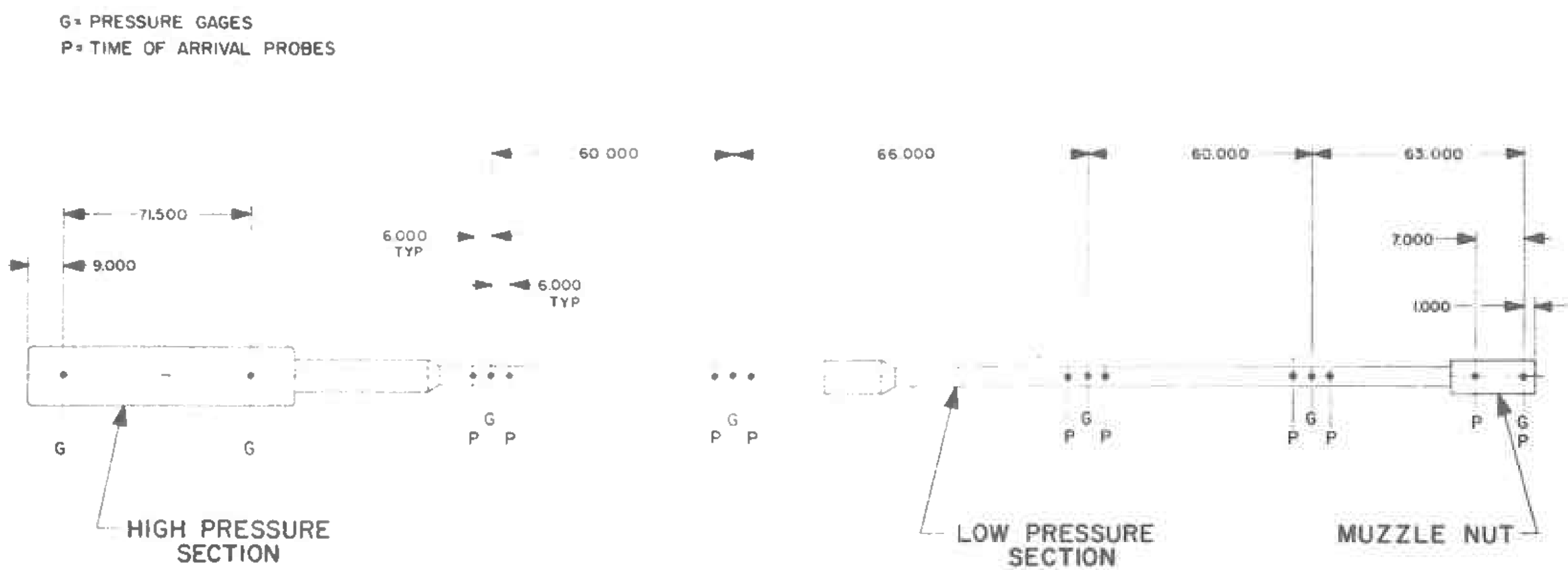

FIG. 7 DIAGRAM OF GAGE AND PROBE LOCATIONS IN THE 1.5-IN. HYPERSONIC SHOCK TUNNEL No. 1.

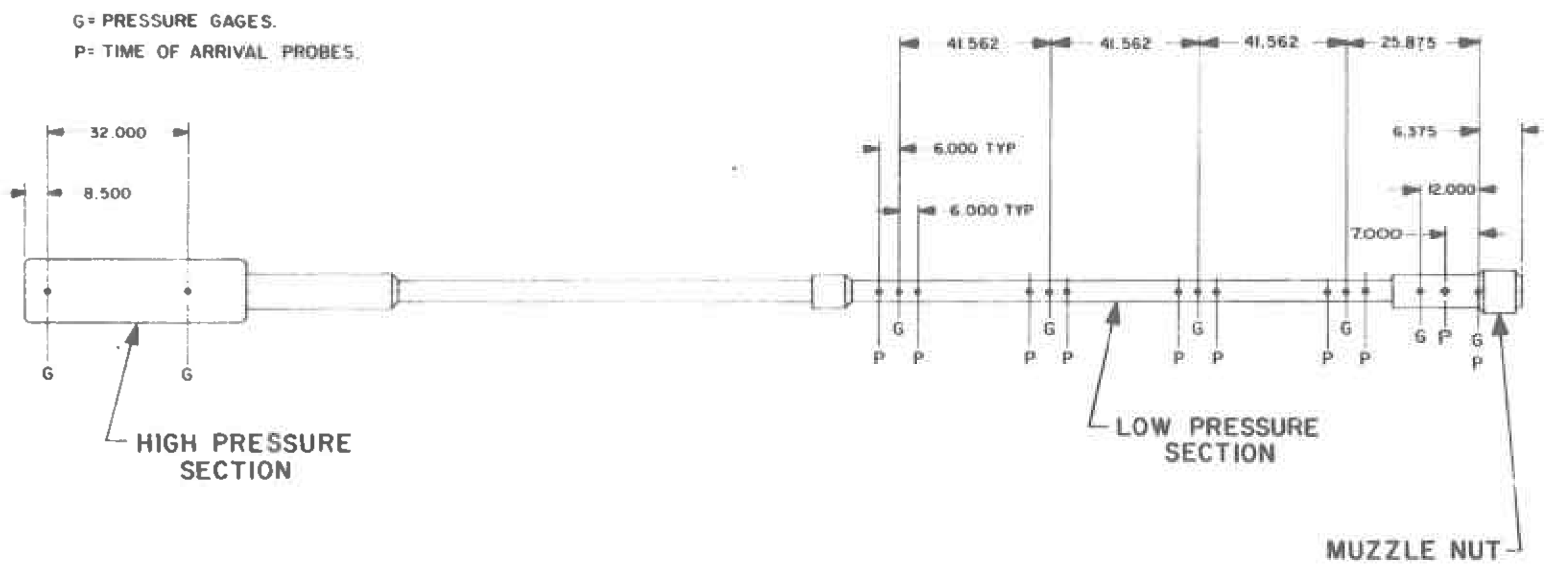

FIG. 8 DIAGRAM OF GAGE AND PROBE LOCATIONS IN THE 1.5-IN. HYPERSONIC SHOCK TUNNEL No. 2.

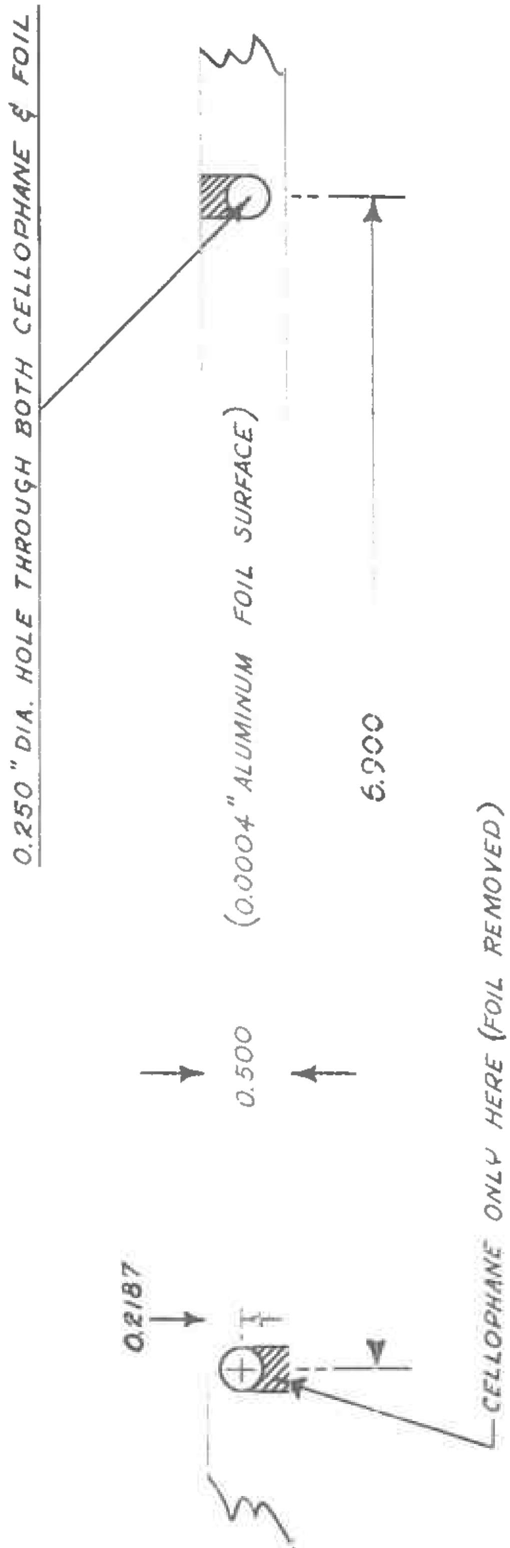

FIG. 9 EXPLODING FOIL IGNITION TAPE.

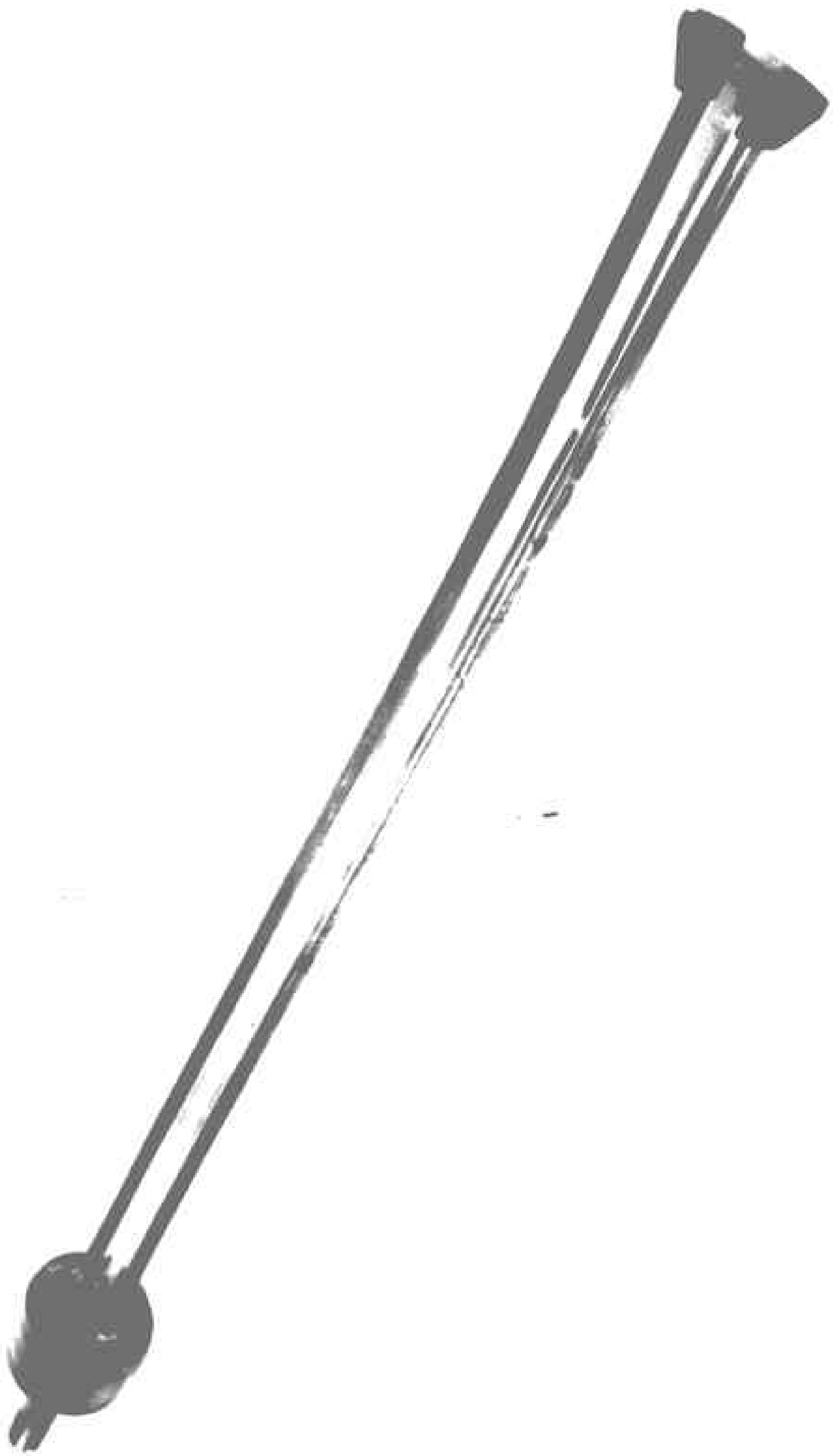

FIG. 10 FIRING ROD BREECH PLUG AND IGNITION TAPE ASSEMBLY.

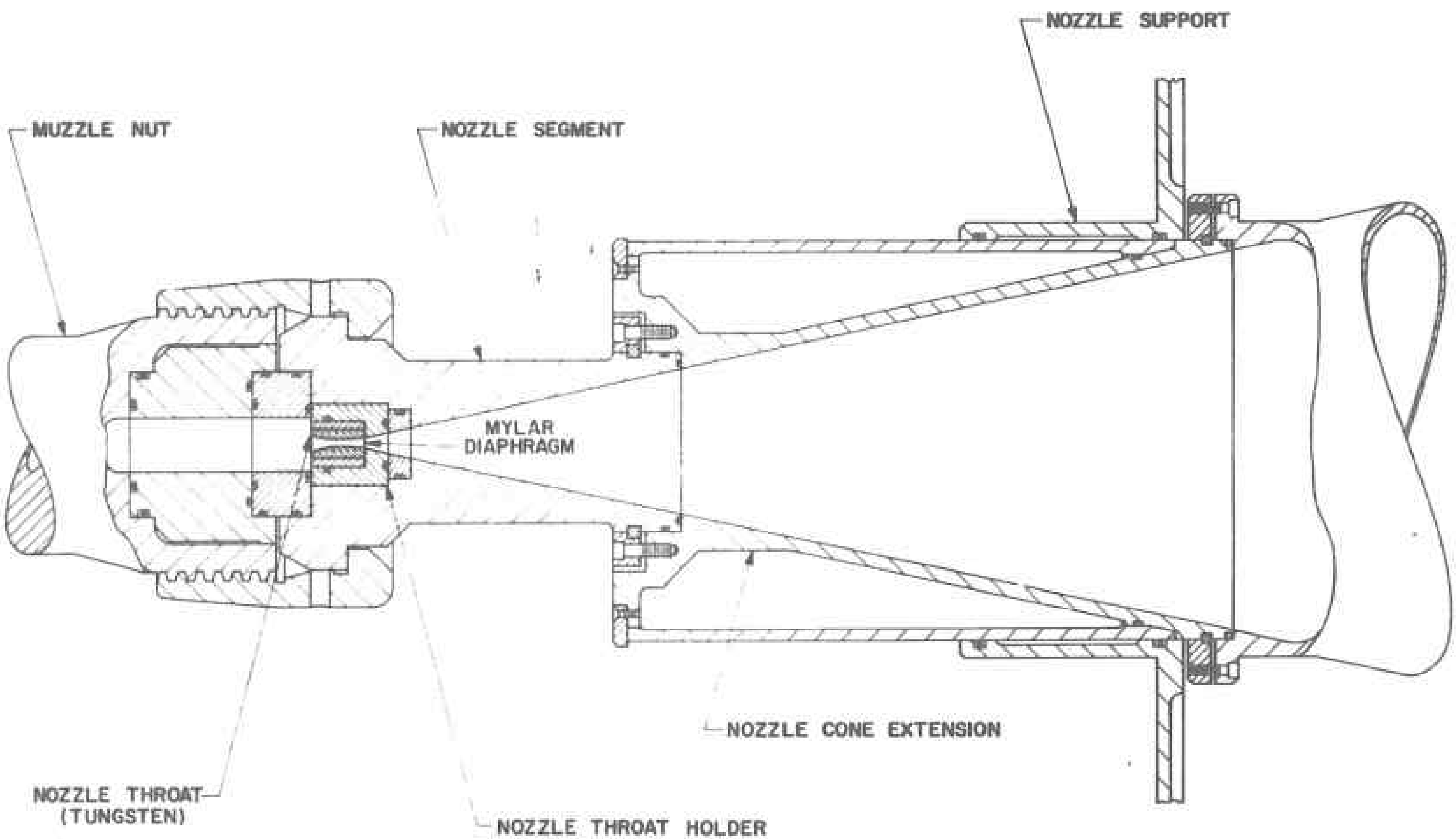

FIG. 11 NOZZLE SECTION OF THE 1.5-IN. HYPERSONIC SHOCK TUNNEL No. 2.

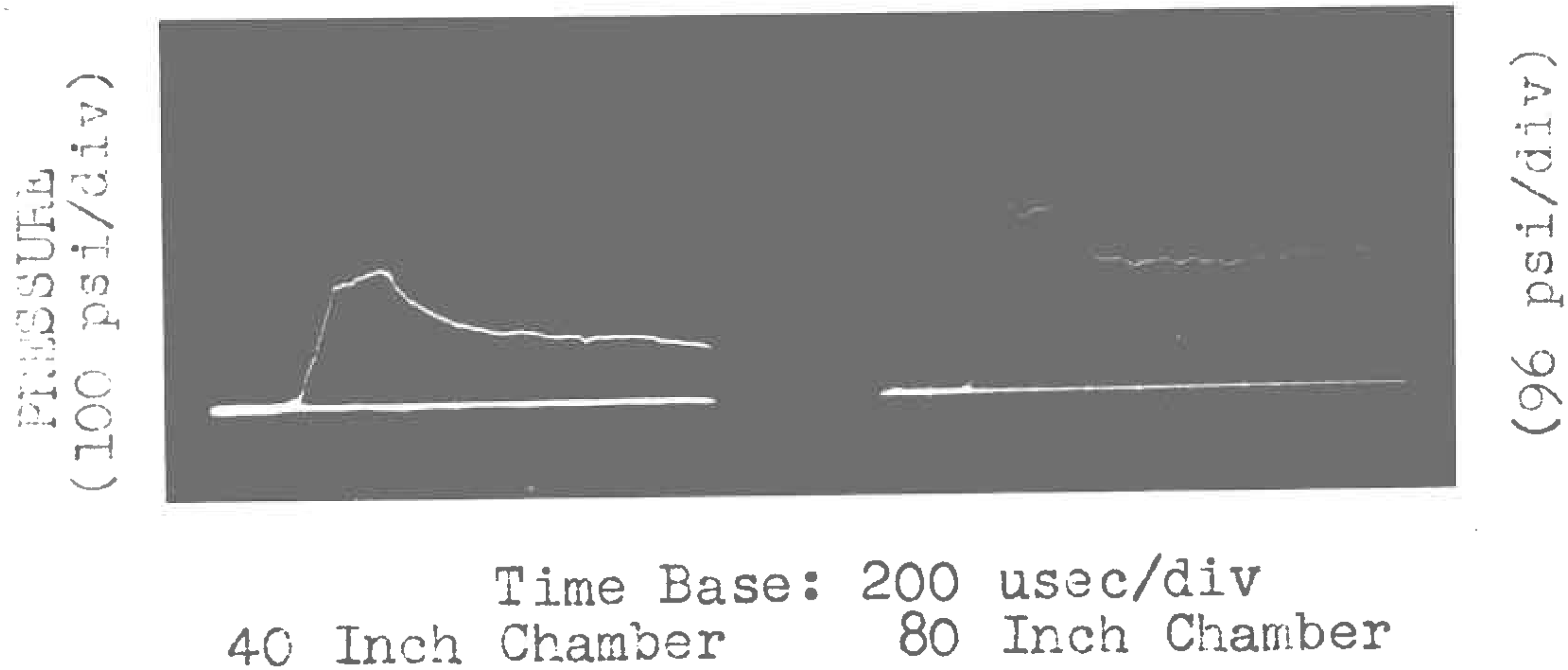

FIG. 12 EFFECT OF SINGLE AND DOUBLE LENGTH DRIVER SECTIONS ON TEST SECTION PITOT PRESSURE.

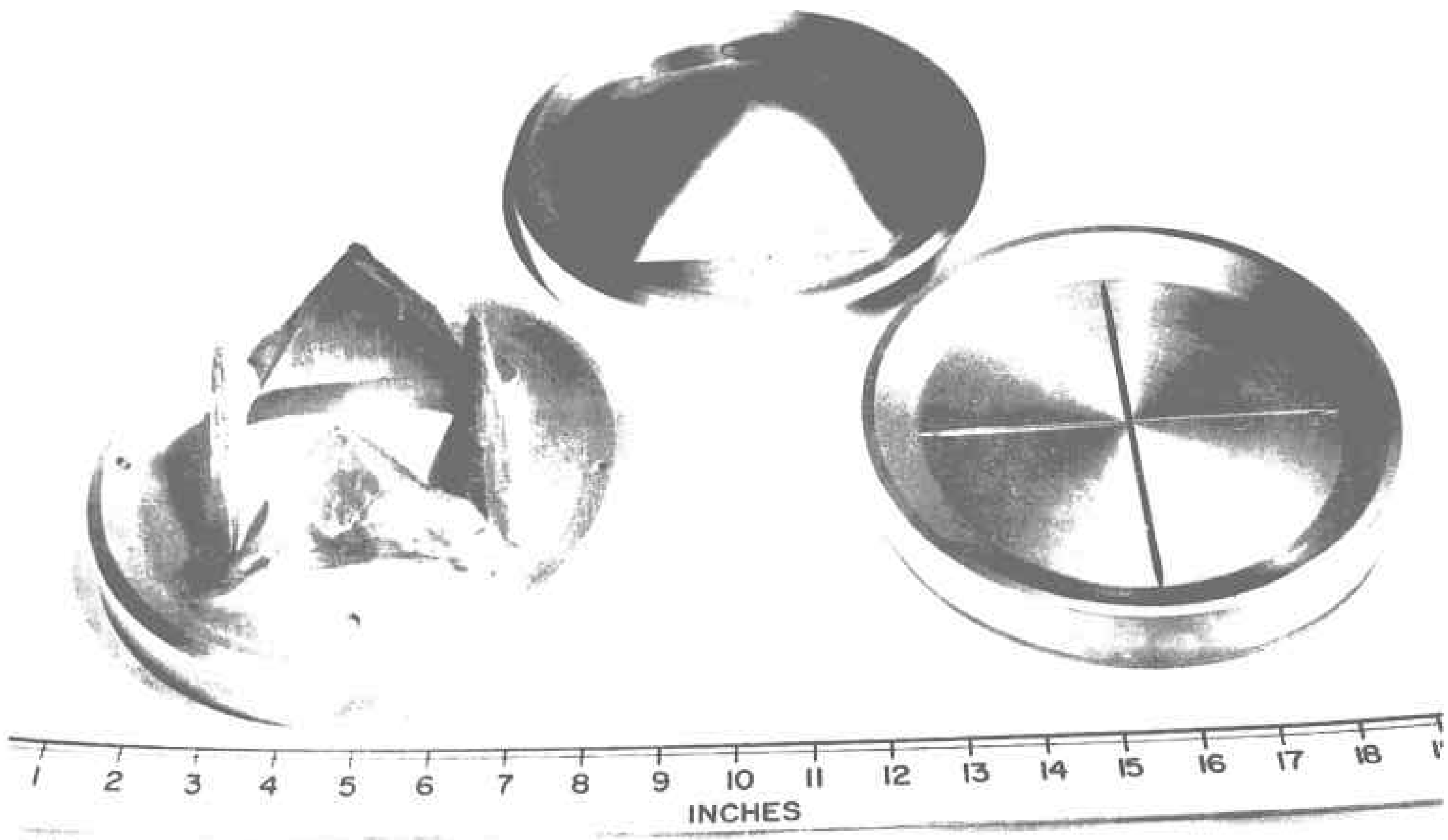

FIG. 13 HIGH PRESSURE SECTION DIAPHRAGMS FOR THE 4-IN. HYPERSONIC SHOCK TUNNEL No. 3.

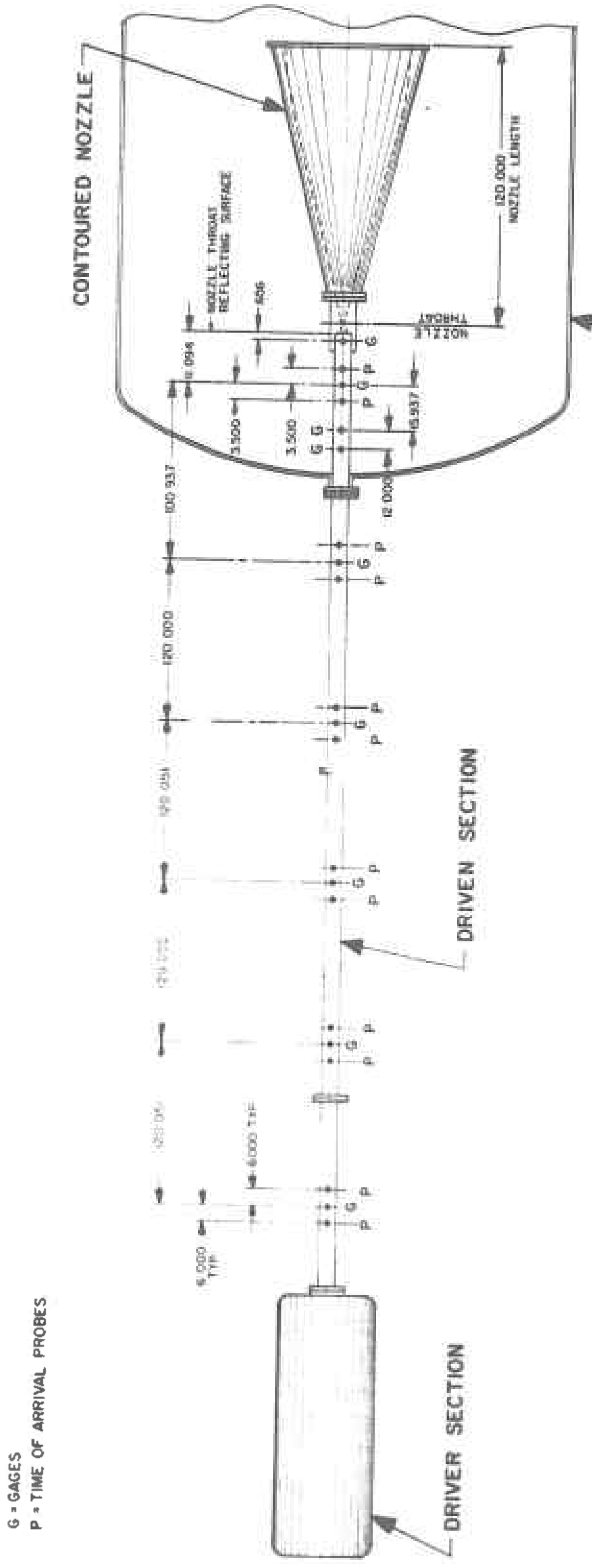

FIG. 14 DIAGRAM OF GAGE AND PROBE LOCATIONS IN THE 4-IN. HYPERSONIC SHOCK TUNNEL No. 3.

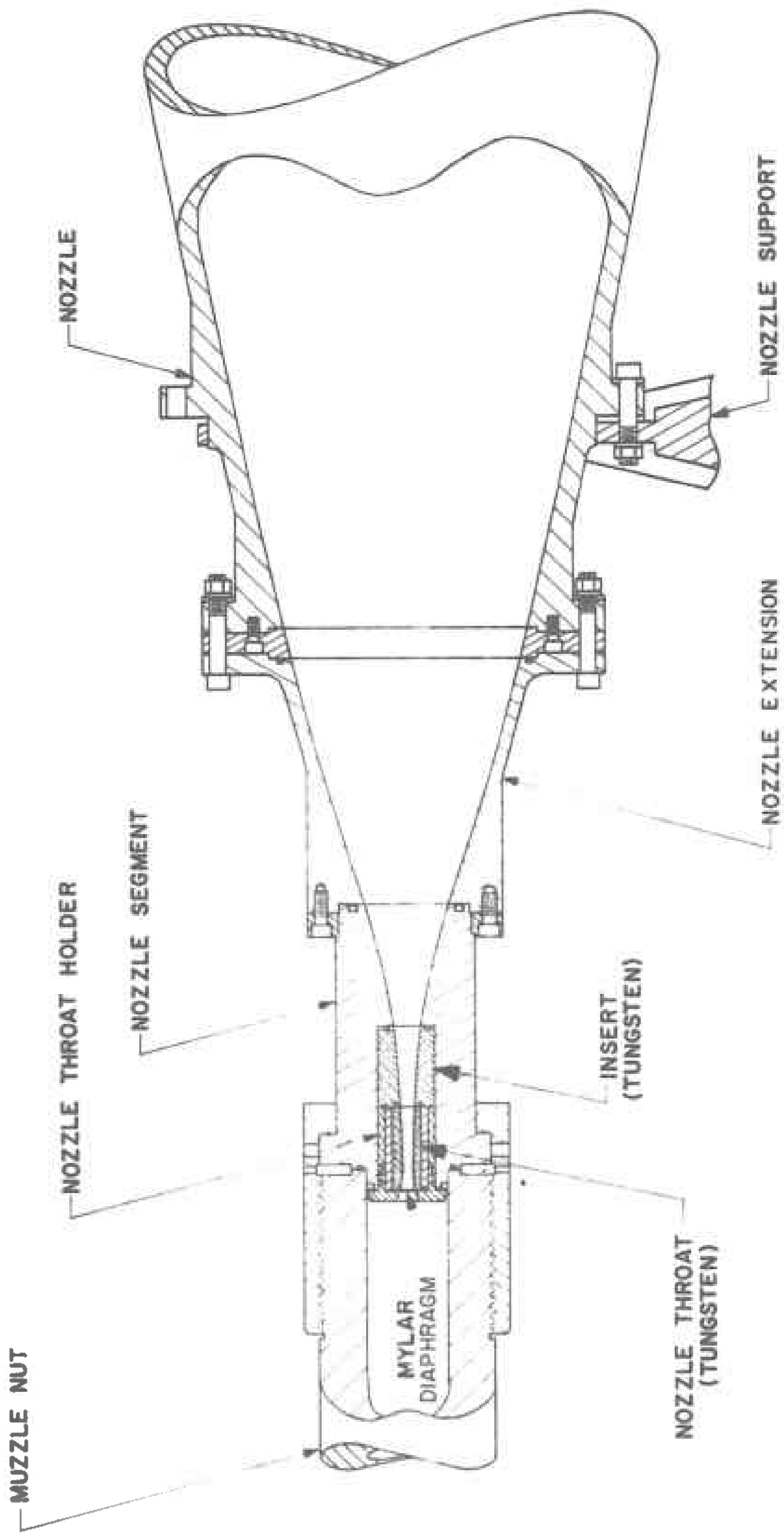

FIG. 15 NOZZLE SECTION OF THE 4-IN. HYPERSONIC SHOCK TUNNEL No. 3.

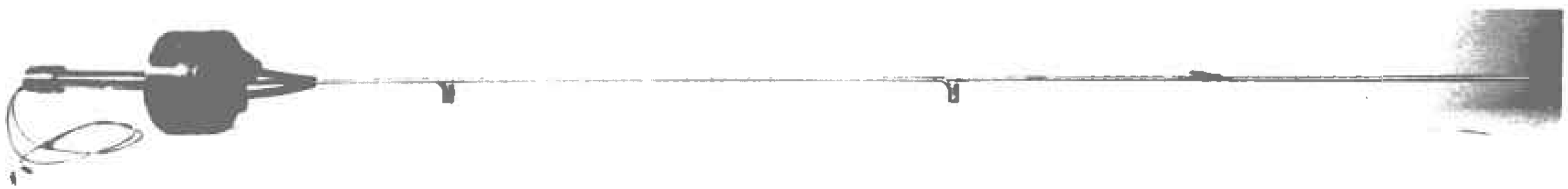

FIG. 16 PRIMER ROD AND BREECH OBTURATING CUP FOR THE 4-IN. HYPERSONIC SHOCK TUNNEL No. 3.

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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
NOL	NOLA				
Hypersonic	HYPR				
Shock tunnel	SHTU				
Facilities	TESF				
Capabilities	CAPB				
Limitations	LIMT				
Instrumentation	INSM				
1.5	1X5Ø				
4	4XØØ				
Inch	INCH				

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-259)
NOL HYPERSONIC SHOCK TUNNEL FACILITIES (U), by J. W. Watt and P. M. Aronson. Dec. 1963. 7p. illus., diagrs., charts. (Ballistic research report 120)

UNCLASSIFIED

This report includes a description of the capabilities and the limitations of the NOL hypersonic shock tunnel facilities presently in operation, and a discussion of some of the associated instrumentation used with these facilities.

Abstract card is unclassified.

1. Shock tunnels, Hypersonic
2. Shock tunnels - Naval Ordnance Laboratory

I. Title
II. Watt, James W.
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